Top Quark Mass Measurements

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for the CDF and DØ collaborations

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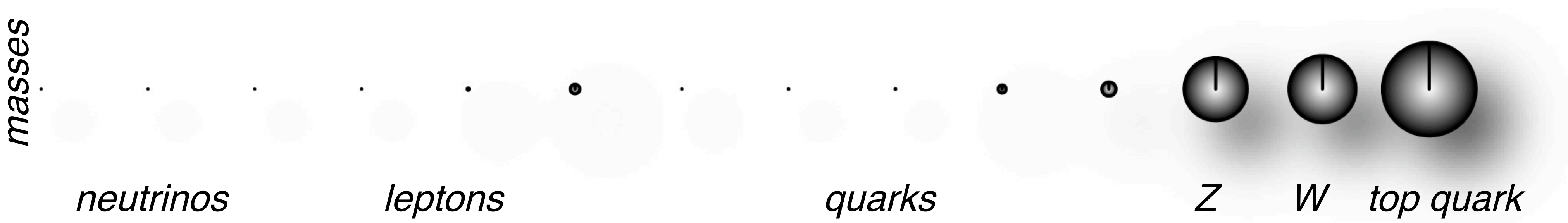
The top quark

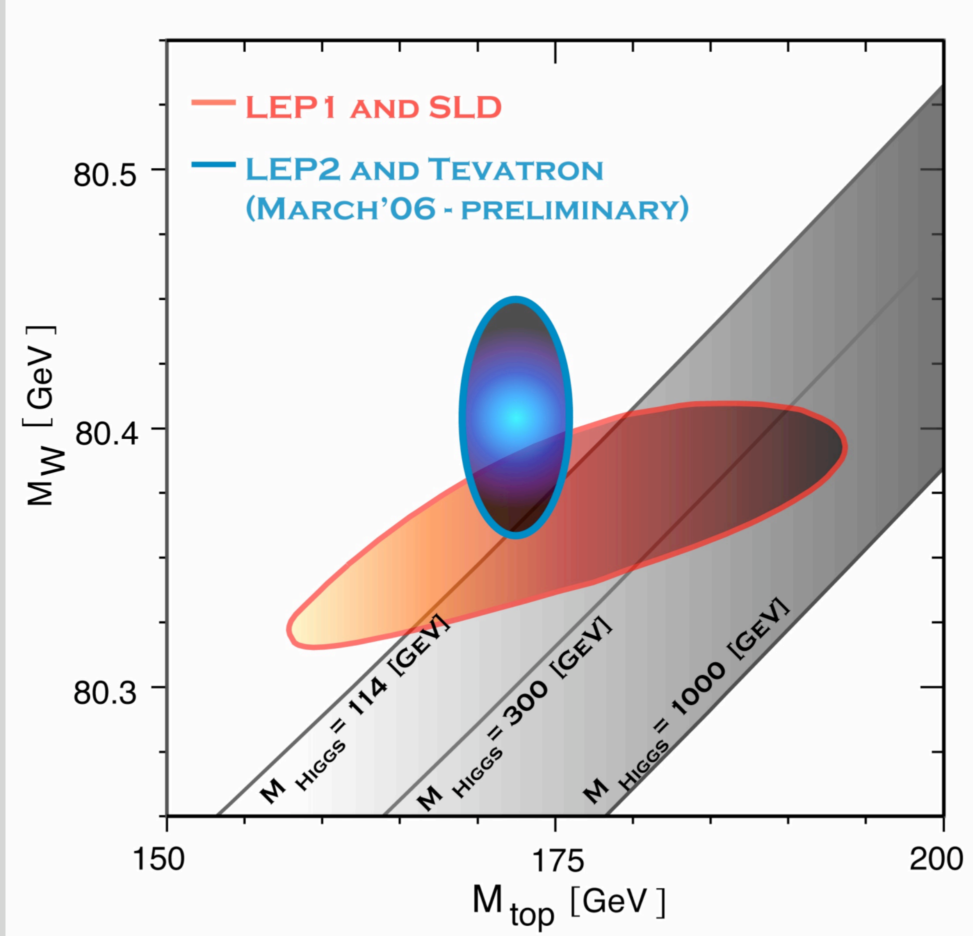
- The top quark is distinguished from other fermions by its huge mass



- As a consequence, the top quark plays a special role in the Standard Model
- Top is the only fermion for which the coupling to the Higgs is important

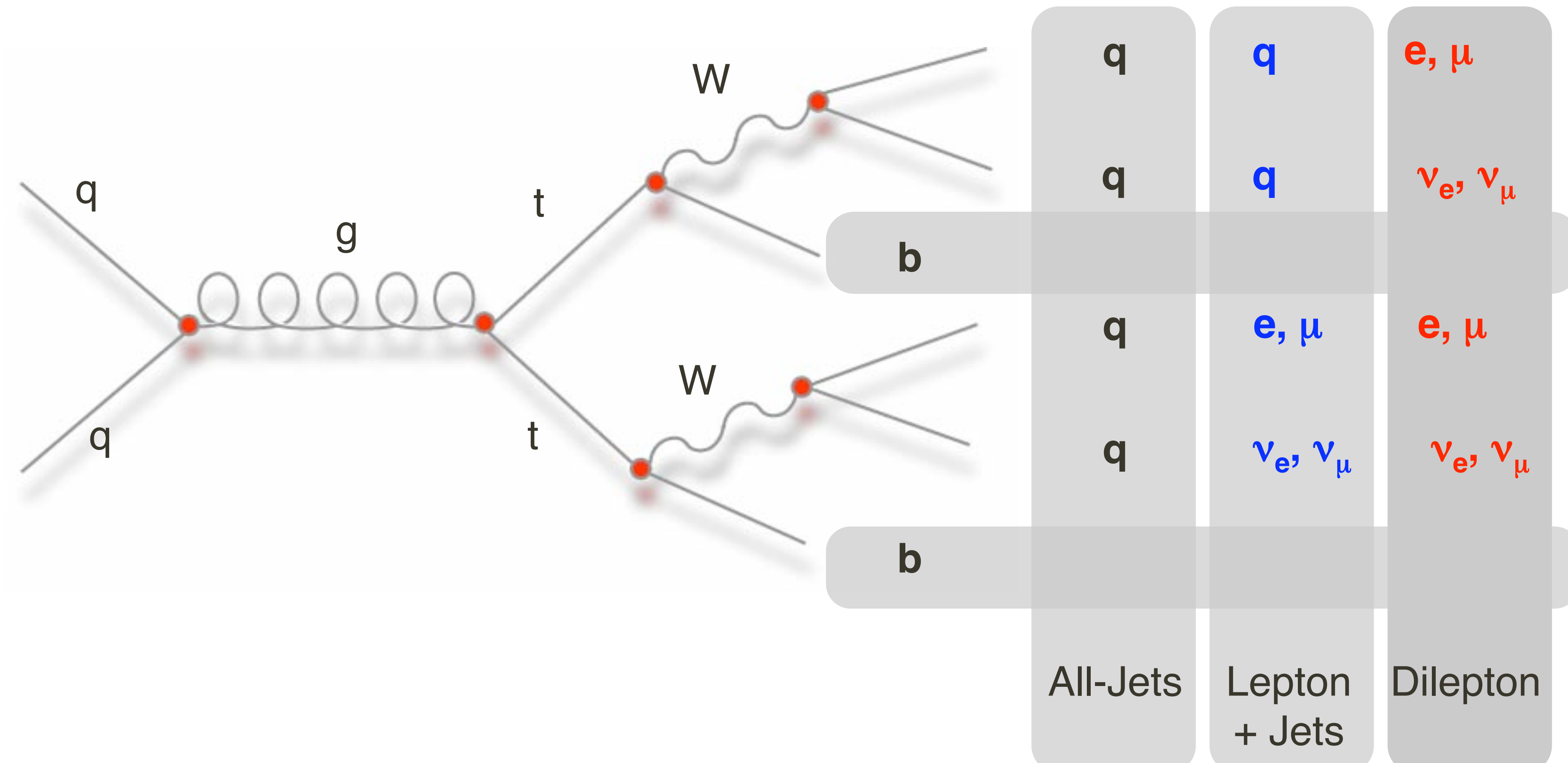
Precision M_{top} measurements

- Allows for prediction of the mass of the Higgs boson
- Constraint on Higgs can point out to physics beyond the standard model
- Consistency checks of the standard model parameters



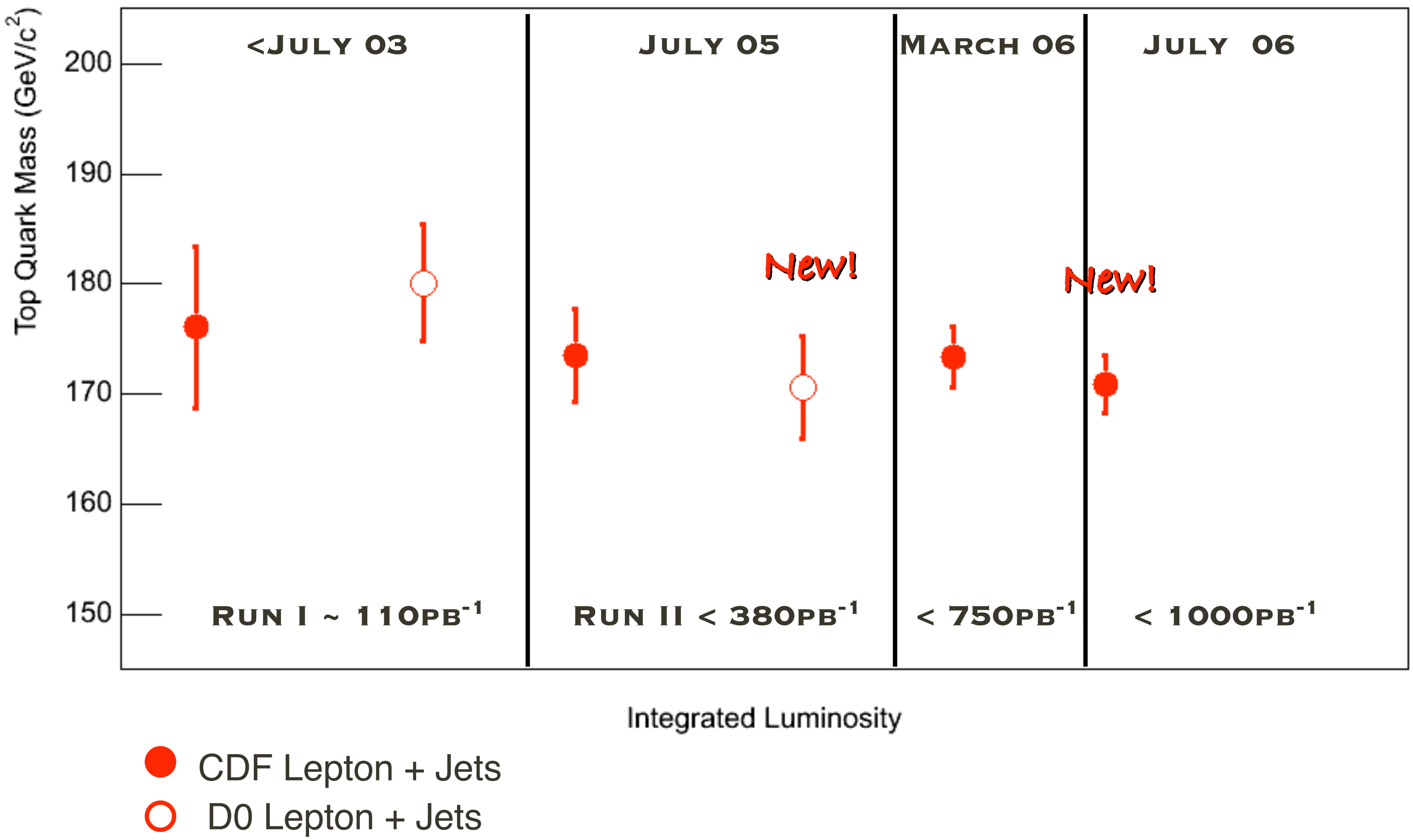
Top quark production and decay

- At the Tevatron produced mainly in pairs and it decays before hadronizing



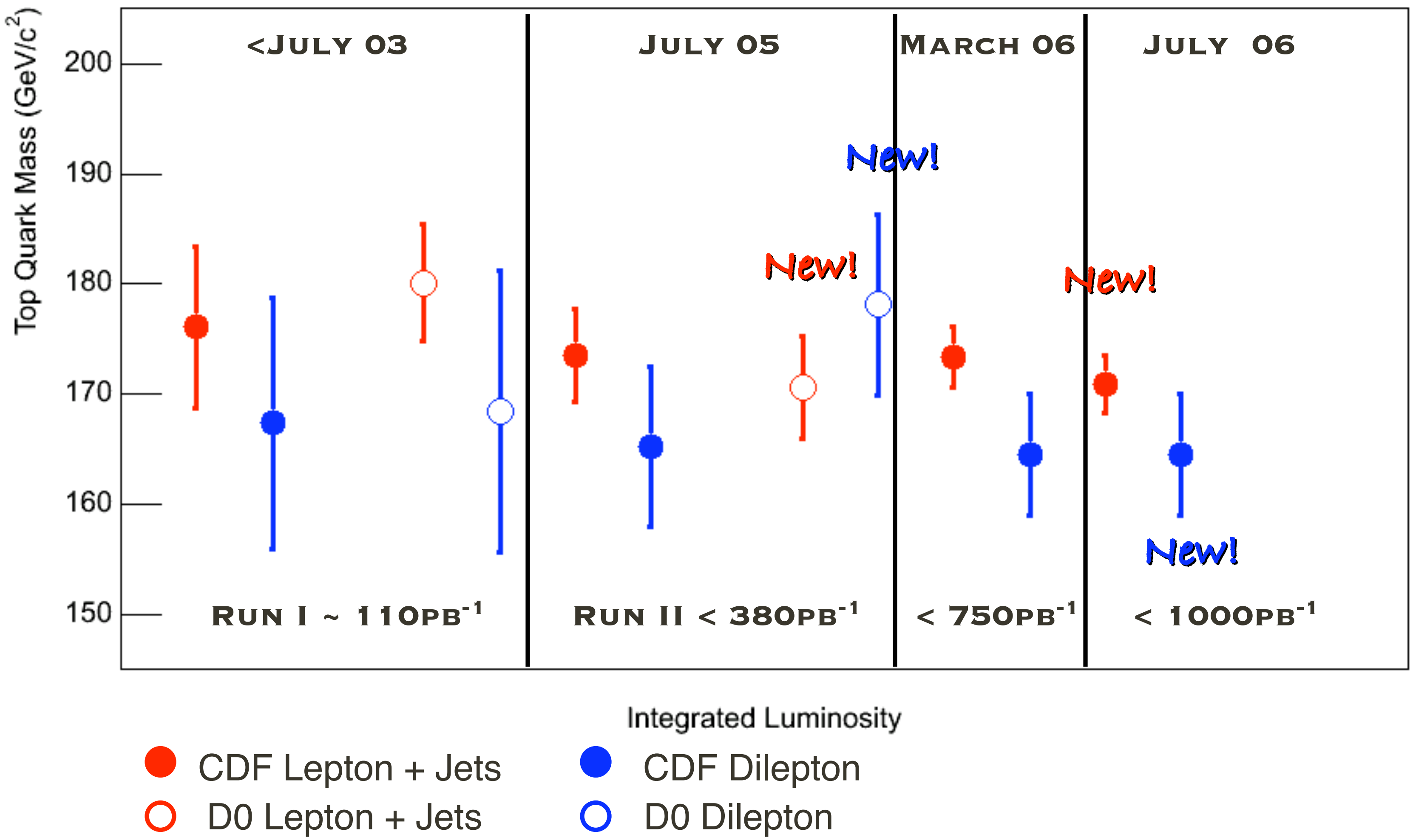
- 3 different channels with different sensitivity and challenges

M_{top} measurements



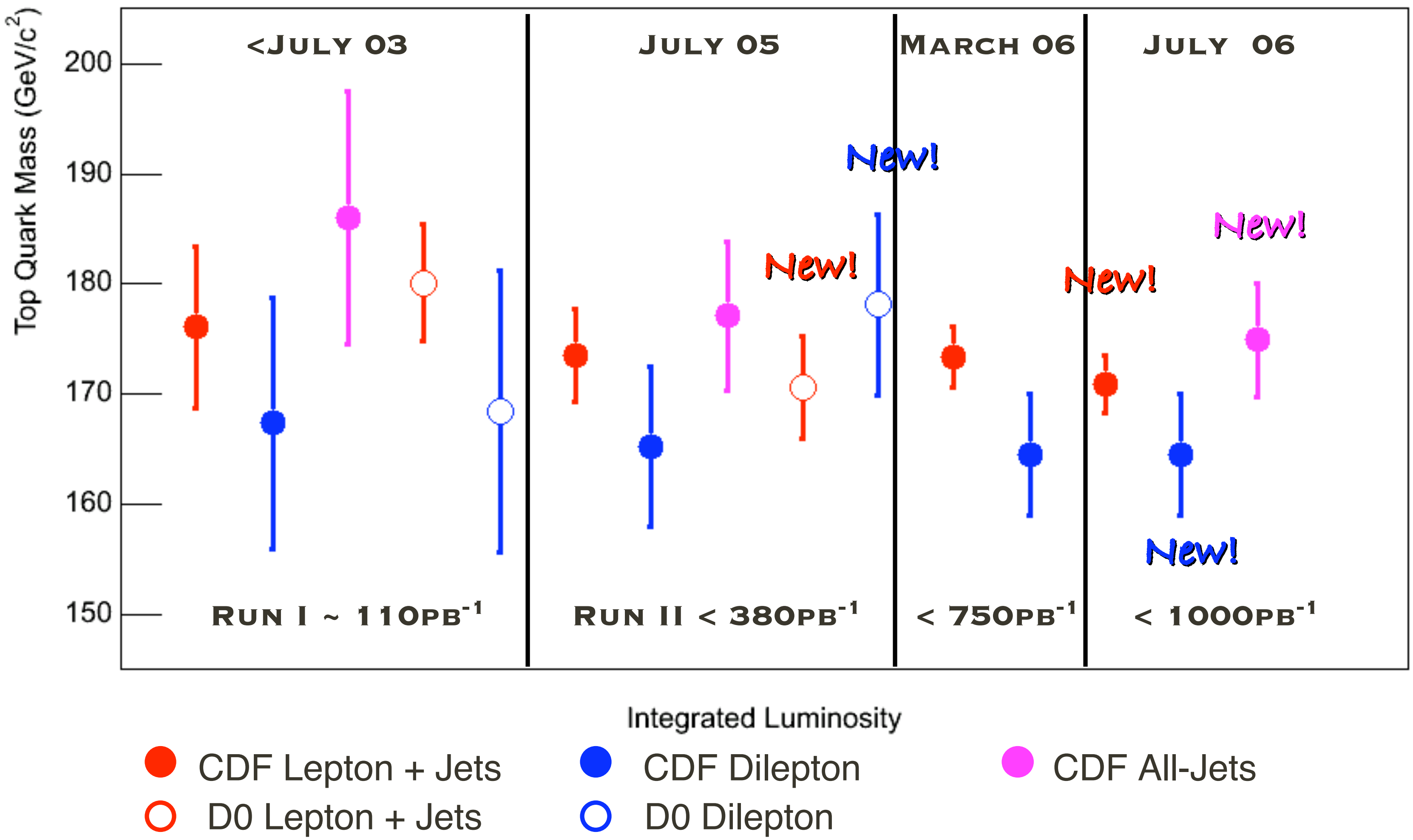
- The most sensitive results

M_{top} measurements



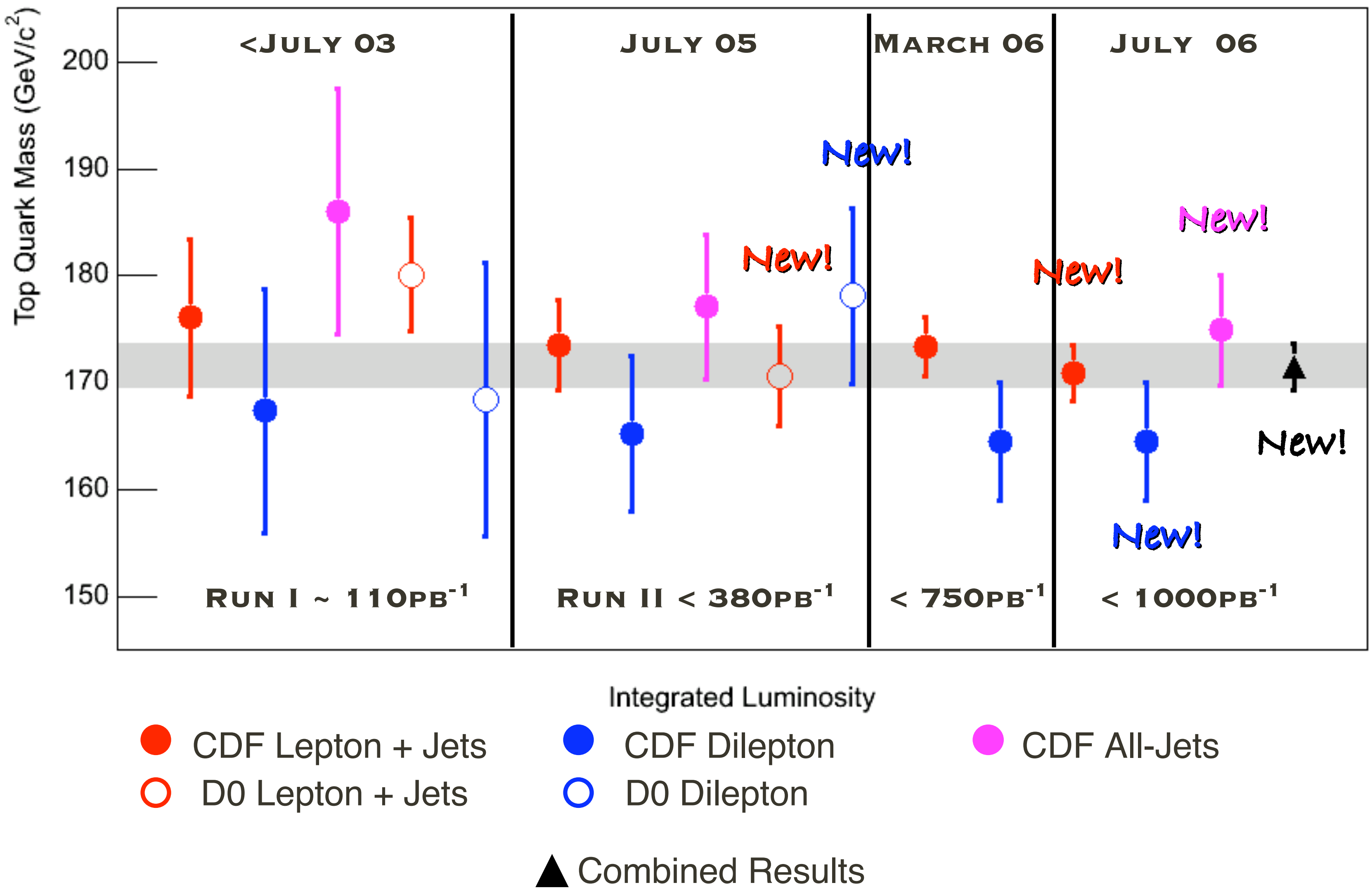
- About half as precise but provides a consistency check among channels

M_{top} measurements



- For the first time systematically dominated!

M_{top} measurements



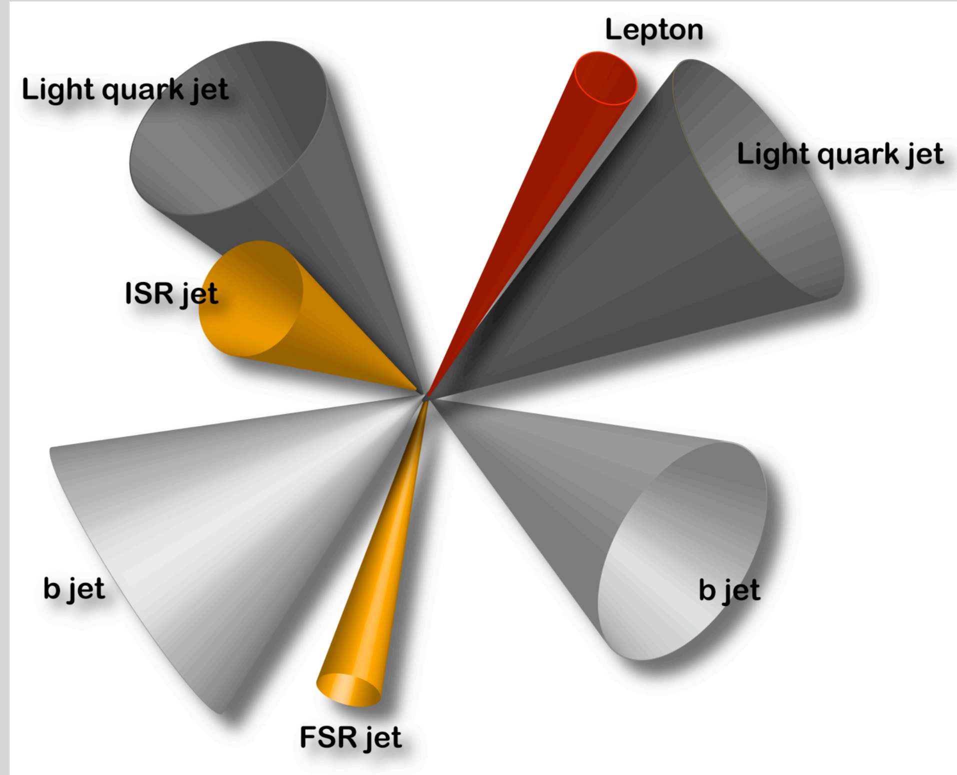
- A new combination adding all the best results in each channel

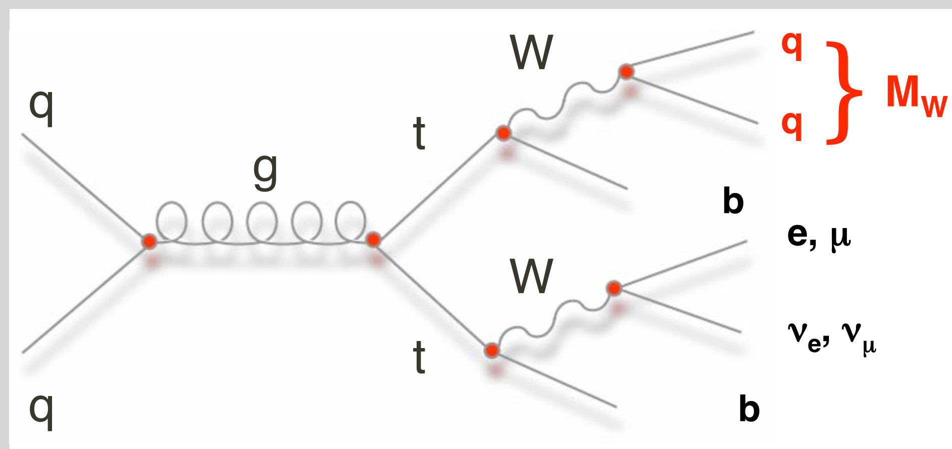
Extraction Techniques

- Need to extract M_{top} from imprecise measurements (jets) and non-measured (neutrino) quantities
- Template analyses:
  - Evaluate a variable strongly correlated with M_{top}
  - Obtain M_{top} comparing data to Monte Carlo with different M_{top} input
- Matrix Element analyses:
  - Evaluate ttbar and background probabilities as a function of M_{top}
  - Obtain M_{top} multiplying event probabilities
- Systematic uncertainties dominated by the uncertainty on parton energies (*Jet Energy Scale, JES*)

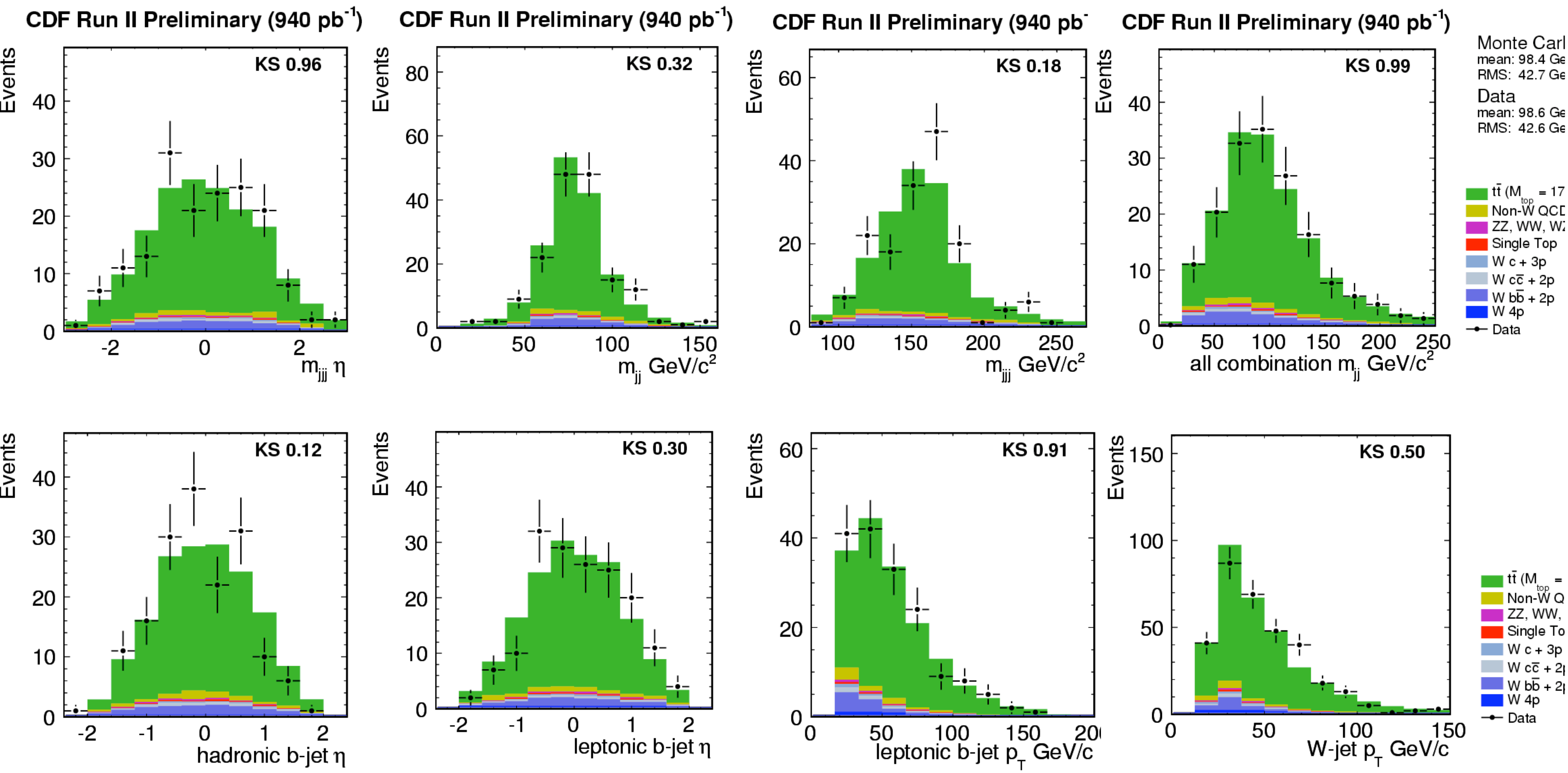
Lepton + Jets

- Final state: one high p_T lepton, missing transverse energy, and 4 or more jets
- Good branching fraction (~30%) and high S:B = 1:4 to 11:1 (depending on the number of b-tags)
- Main background: *W + jets*
- Combinatorial background :12 combinations
- JES can be measured in the same sample (*JES in-situ*)





Lepton + Jets



- Good agreement between data and Monte Carlo

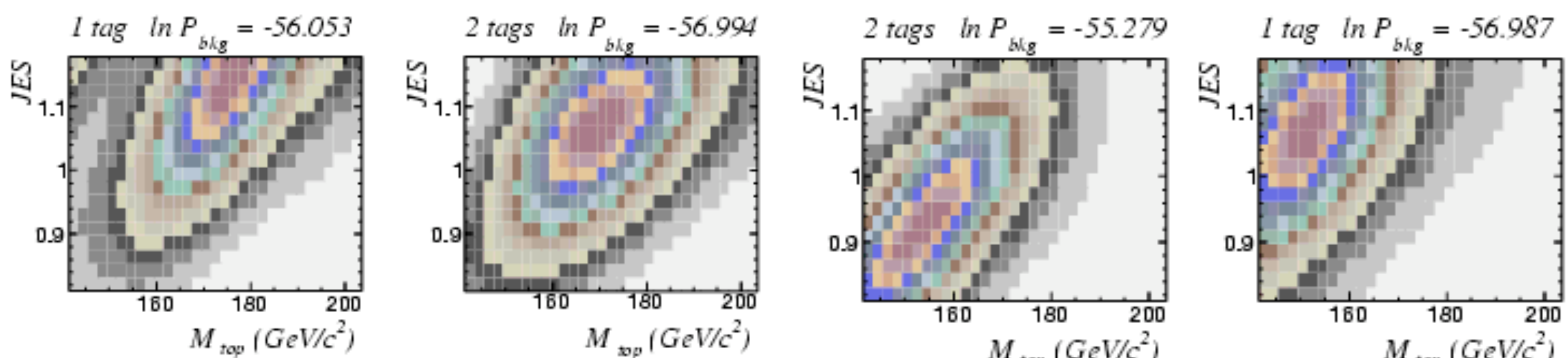
Lepton + Jets

- These analyses were designed to optimize the use of kinematic and dynamic information
  - Probability for a *tt* and *W+jets* hypothesis (Matrix Element Method)
  - Integrate over all the unmeasured quantities and experimental resolutions

$$\bar{P}(x;M_{top},JES) = \frac{1}{\sigma}\int d^n\sigma(y;M_{top})\,dq_1\,dq_2\,f(q_1)\,f(q_2)\,W(JES,x,y)$$

- Likelihood used to fit simultaneously M_{top}, JES, and signal fraction, C_s

$$L(C_s,M_{top},JES) \propto \prod_{i=1}^{Nevents}(C_s\,P_{ttbar,i}(M_{top},JES) + (1-C_s)\,P_{W+jets,i}(JES))$$



Lepton + Jets

- CDF has used 940 pb^{-1} and measured with 166 candidates with at least one b-tagged jet

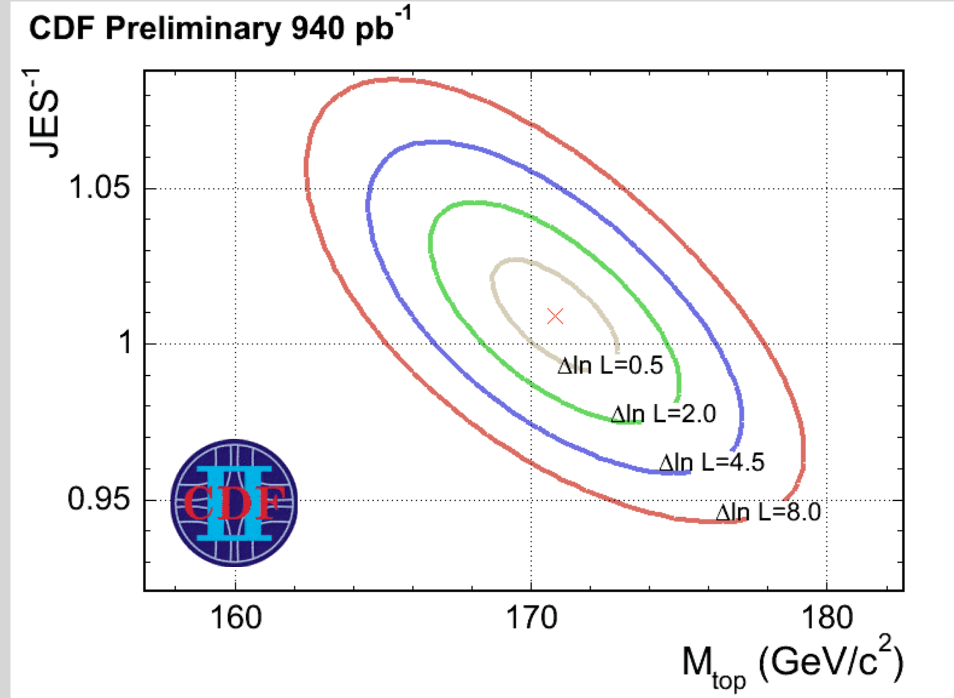
$$M_{top} = 170.9 \pm 1.6\,(\text{stat.}) \pm 1.4\,(\text{JES}) \pm 1.4\,(\text{syst.})\,\text{GeV}/c^2$$

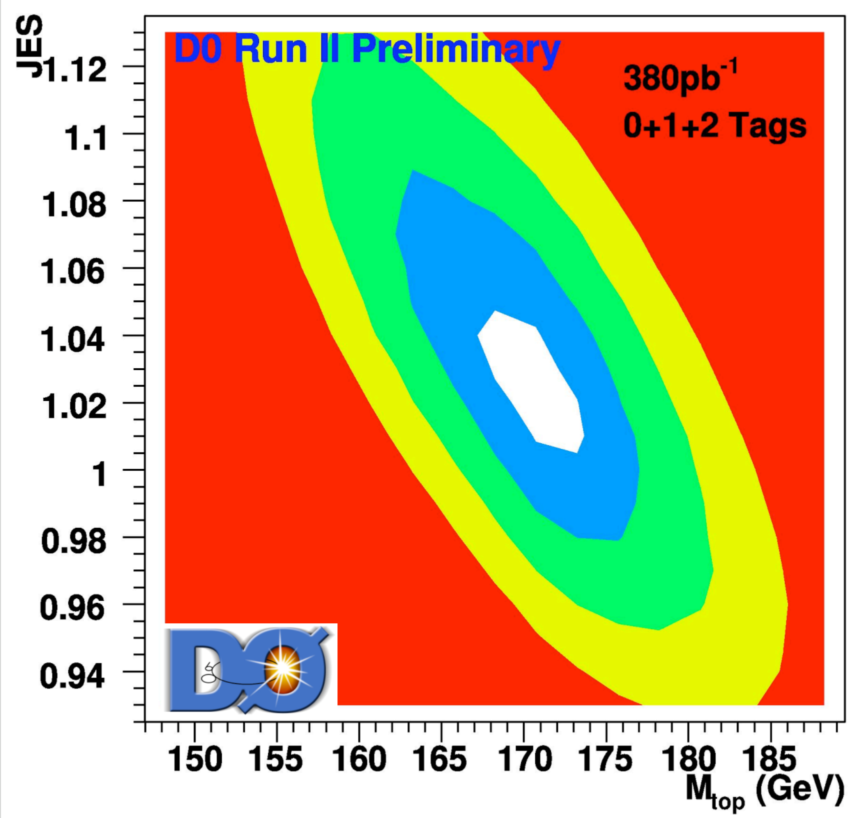
Most precise world measurement

1 fb^{-1}

- D0 has used 370 pb^{-1} and measure with 175 candidates with and without b-tagging requirement

$$M_{top} = 170.3 \pm 2.5\,(\text{stat.}) \pm 3.5\,(\text{JES}) \pm 1.5\,(\text{syst.})\,\text{GeV}/c^2$$





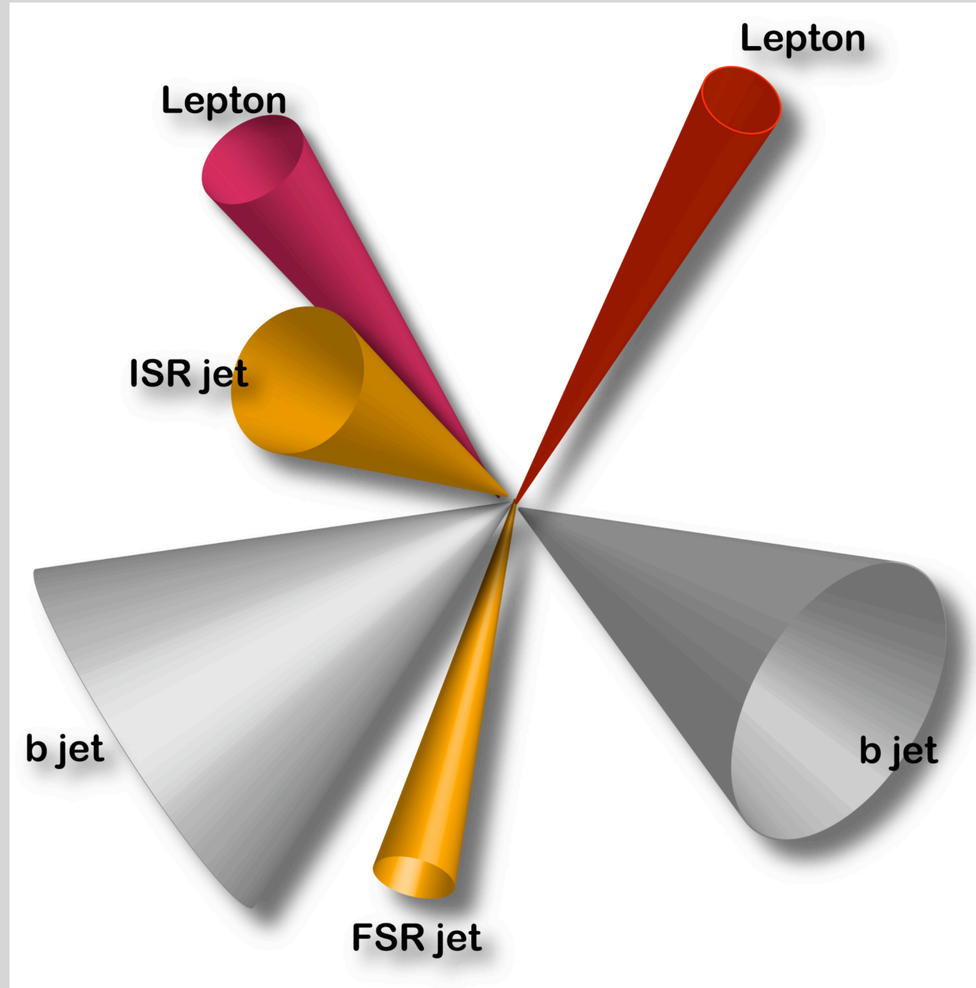
Lepton + Jets

- The other systematic uncertainties

Source of uncertainty	**CDF Magnitude (GeV/c^2)**
b-JES	0.6
Signal (Initial and final state radiation, parton distribution functions)	1.1
Background (composition and shape)	0.2
Fit (Method, Monte Carlo statistics)	0.4
Monte Carlo (Modeling of ttbar)	0.2
Total	**1.4**

Dilepton

- Final state: 2 high p_T leptons, 2 b-jets, and missing transverse energy from the 2 neutrinos
- Small branching fraction (~5%) and very high S:B = 2:1 (no b-tagging)
- Combinatorial background: 2 combinations
- Main backgrounds: Drell-Yan, fakes
- 2 neutrinos: under constrained, kinematically complicated to solve M_{top}



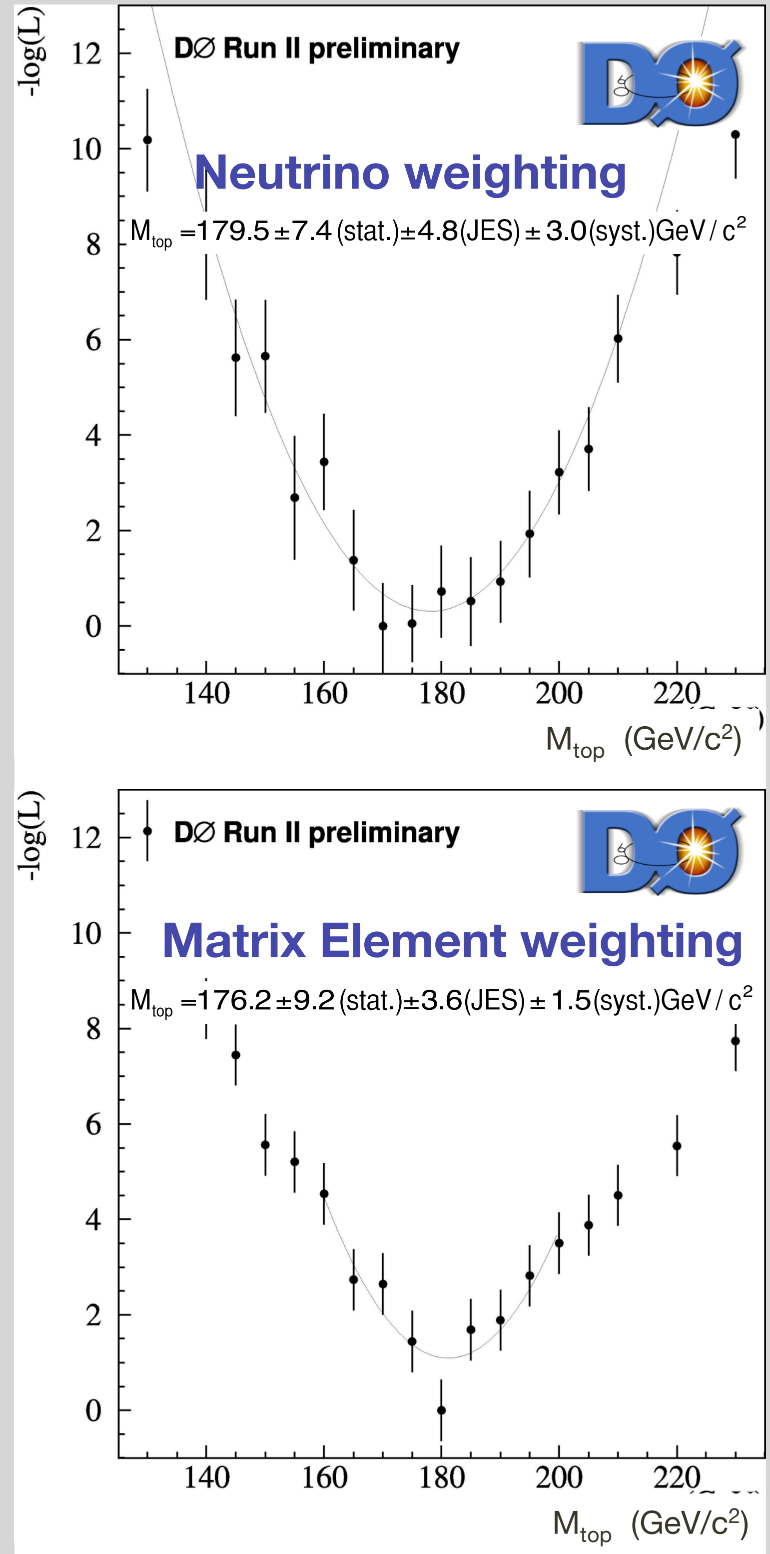
Dilepton

- For an assumed M_{top} there are different kinematical solutions that are consistent with the observed momenta of the final state particles
  - Neutrino weighting
  - Matrix element weighting
- Compare data with Monte Carlo events generated with different M_{top} (templates)
- Using 370 pb^{-1} D0 combine these results and obtains

$$M_{top} = 178.1 \pm 6.7\,(\text{stat.}) \pm 4.3\,(\text{JES}) \pm 2.1\,(\text{syst.})\,\text{GeV}/c^2$$

Neutrino weighting in $e\mu$ channel with 835pb^{-1}

$$M_{top} = 171.6 \pm 7.9\,(\text{stat.}) \pm^{5.1}_{4.0}\,(\text{syst.})\,\text{GeV}/c^2$$



Dilepton

- Probabilities calculated integrating over all the unmeasured quantities and detector resolutions

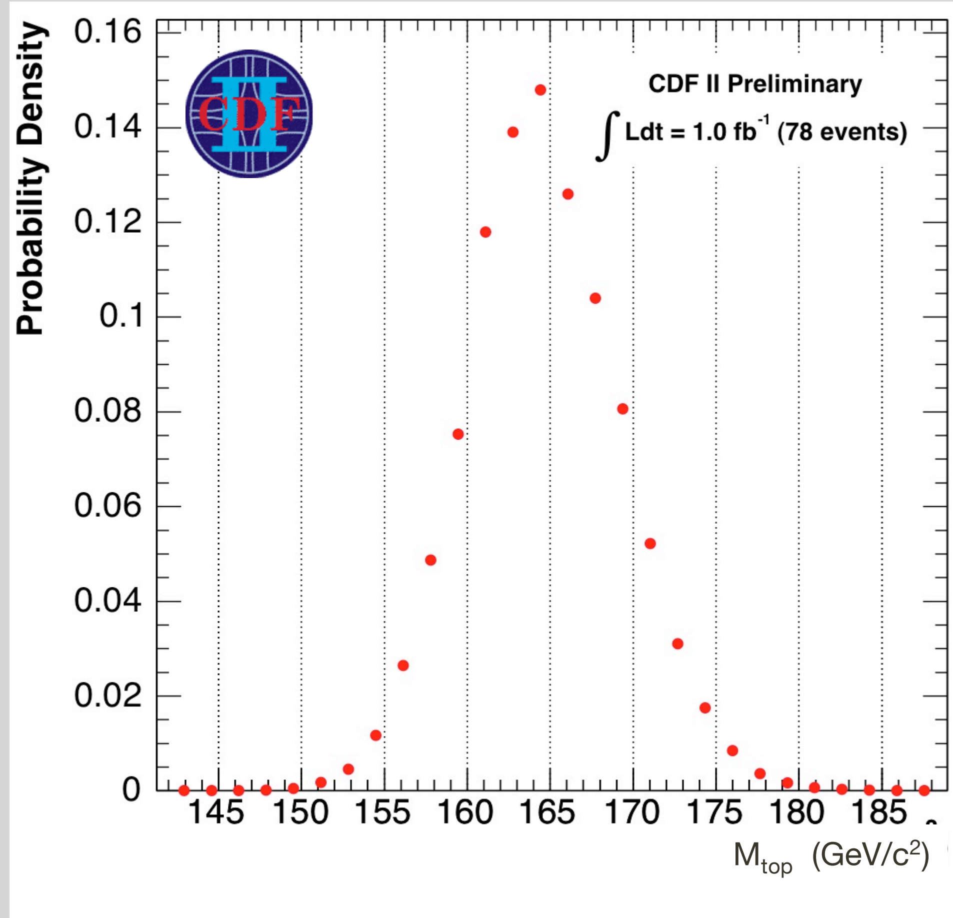
- Using 1030 pb^{-1} and 78 candidates CDF measures

$$M_{top} = 164.5 \pm 3.9(\text{stat.}) \pm 3.5(\text{JES}) \pm 1.7(\text{syst.})\,\text{GeV}/c^2$$

- Cross-check result requiring b-tagging (S:B=11:1)

$$M_{top} = 167.3 \pm 4.6(\text{stat.}) \pm 3.3(\text{JES}) \pm 1.9(\text{syst.})\,\text{GeV}/c^2$$

1 fb^{-1}



All-Jets

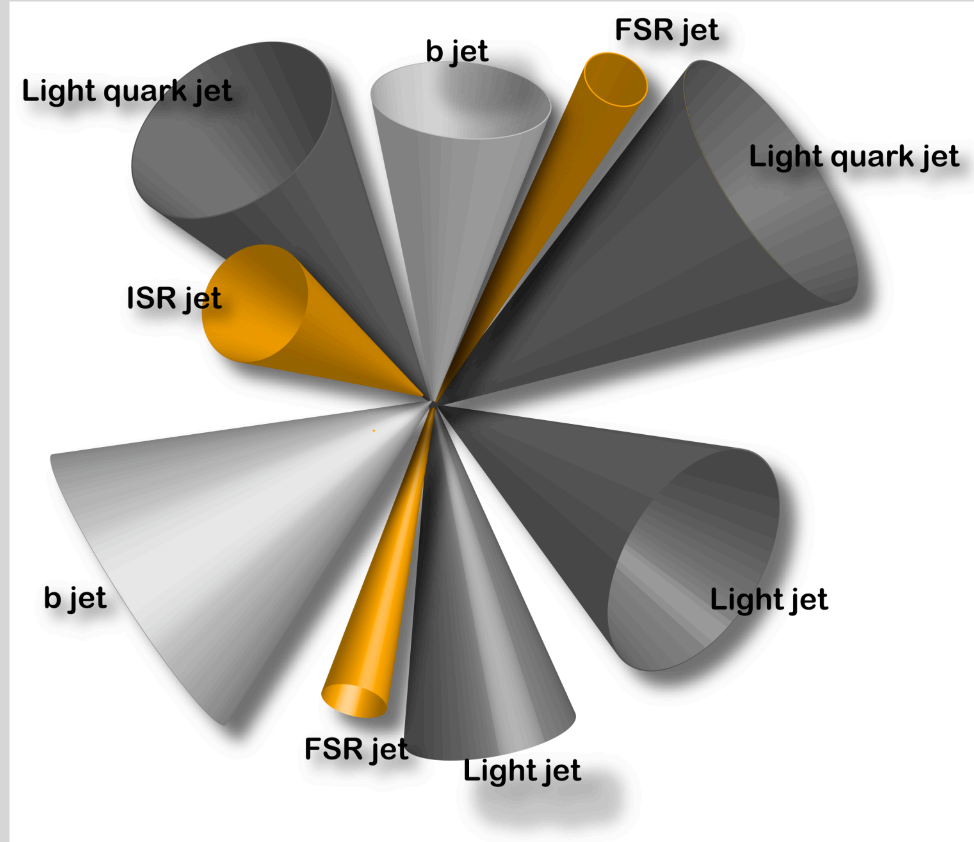
- Final state: 6 high p_T jets

- Very good branching fraction (~44%) but huge amount of background S:B = 1:8 (after requiring b-tagging)

- Combinatorial background: 90 combinations

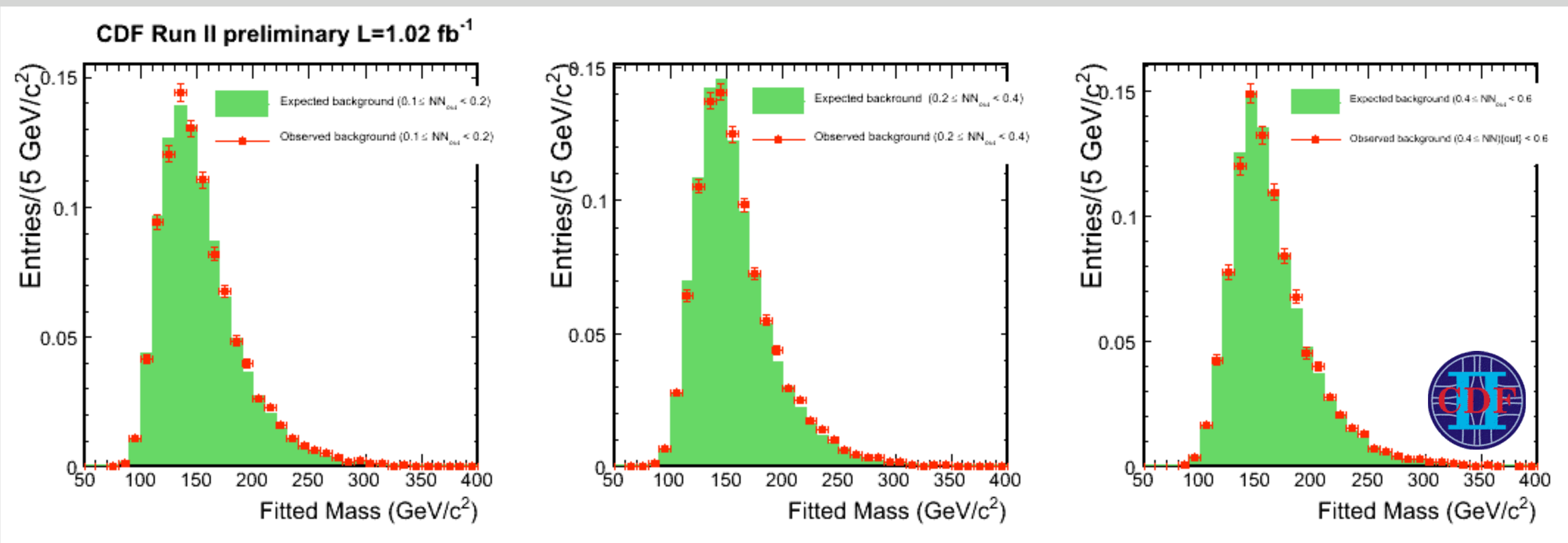
- Main background: multi-jet QCD production

- Could use in-situ JES uncertainty



All Jets

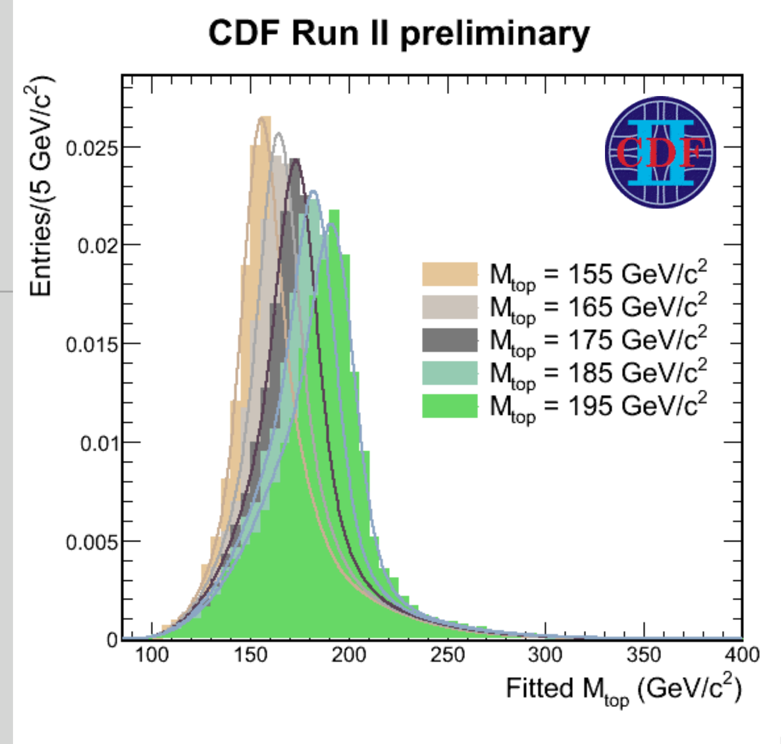
- Use data-driven background obtained before b-tagging jets
- Neural Network selection to improve S/B = 1/2

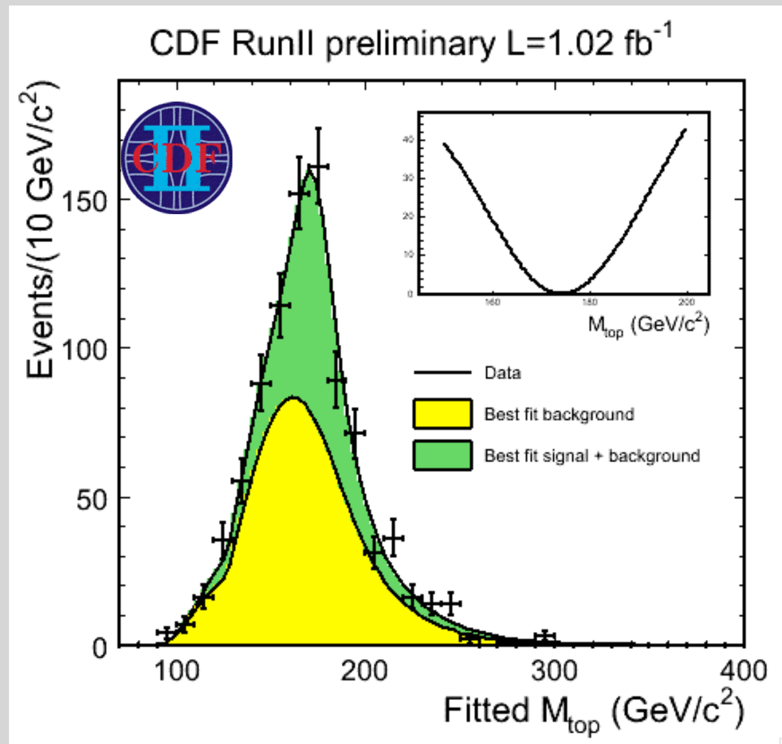


All Jets

- Template method with fitted M_{top}
- $6 \leq N_{jet} \leq 8$ with only the first 6 jets in order of decreasing E_T are used
- Kinematical fitter chooses among 30 possible permutations of jets
- CDF measures using 1020 pb^{-1} with 772 events and S/B=1/2

$$M_{top} = 174.0 \pm 2.2\,(\text{stat.}) \pm 4.5\,(\text{JES}) \pm 1.7\,(\text{syst.})\,\text{GeV}/c^2$$

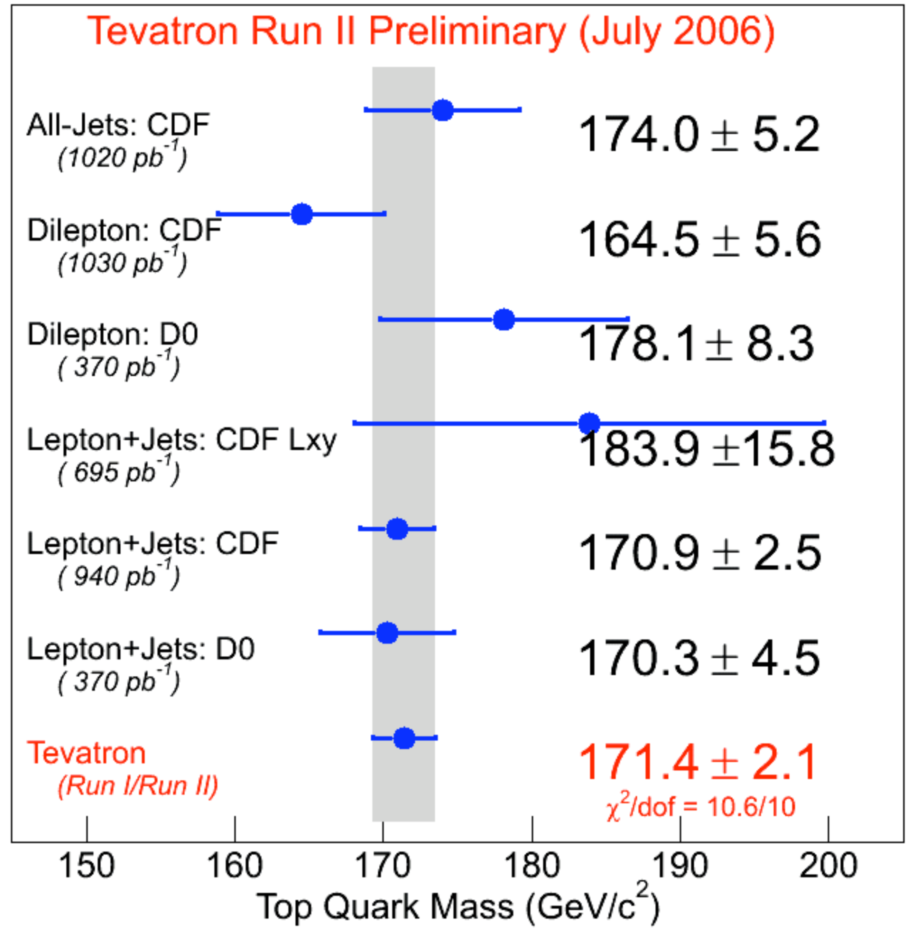




Combination

- Excellent results in each channel
- Combine them to improve precision:
  - Include Run-I results
  - Account for correlations
  - Use Linear Unbiased Estimator (*NIM* ***A270*** *110,* ***A500*** *391)*
  - We reached a precision of 1.2% in M_{top}

$$M_{top} = 171.4 \pm 1.2(\text{stat.}) \pm 1.4(\text{JES}) \pm 1.0(\text{stat.})\,\text{GeV}/c^2$$



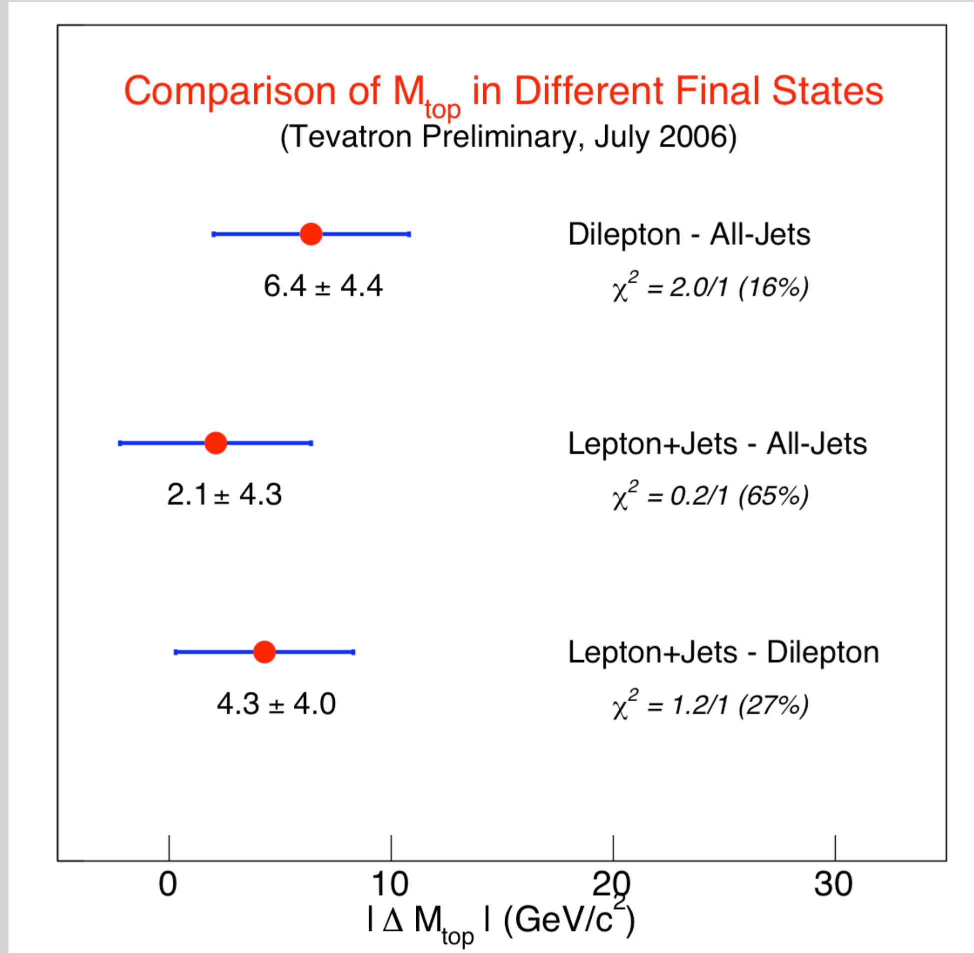
Comparison

- Are the channels consistent?

M_{top}(All Jets) = 173.4 ± 4.3 GeV/c^2
M_{top}(Dilepton) = 167.0 ± 4.3 GeV/c^2
M_{top}(Lepton+Jets) = 171.3 ± 2.2 GeV/c^2

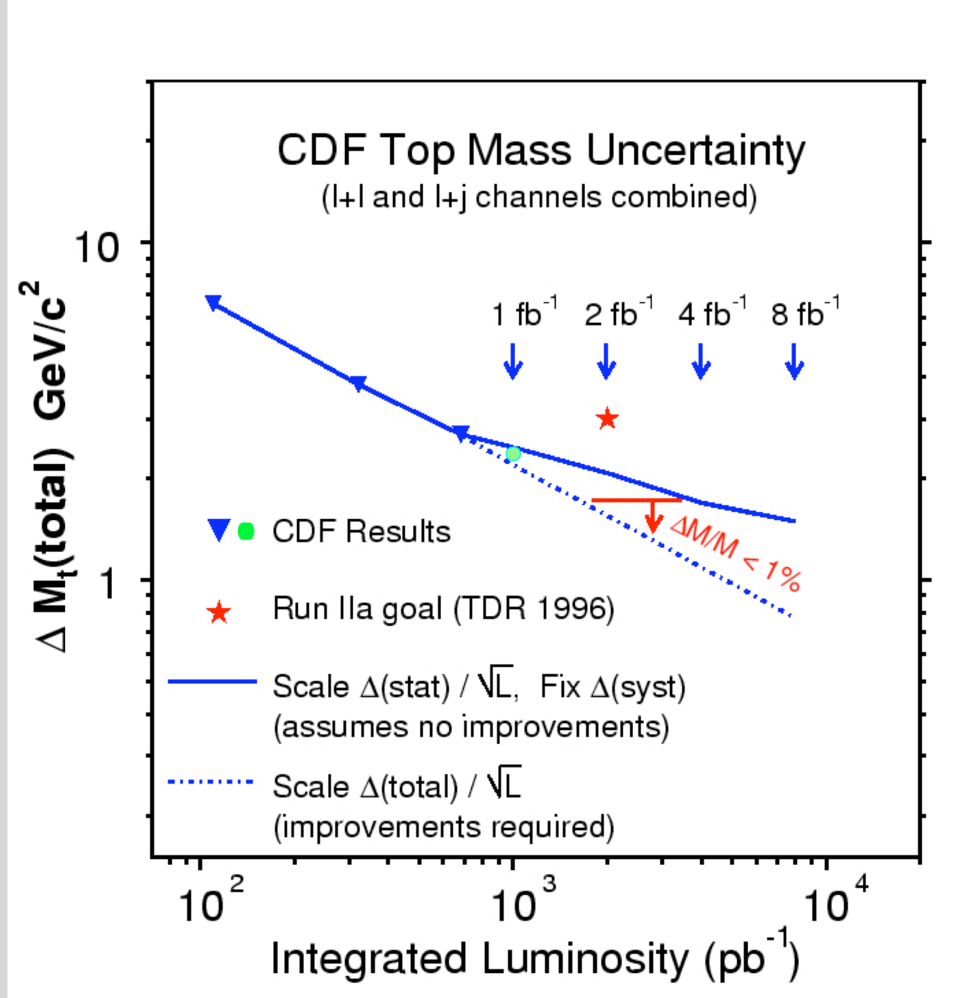
- We compare them taking into account their correlated systematic uncertainties

- Determination of M_{top} from the 3 different channels is consistent with one another



M_{top} future

- New results are better than our predictions 6 months ago
- Will add to the prediction all-jets channel
- Add JES to all-jets could make sensitivity comparable to lepton+jets
- D0 has similar sensitivity (new results with 1fb^{-1} coming soon)
- We expect to achieve an uncertainty of 1 GeV in the next years



Conclusions

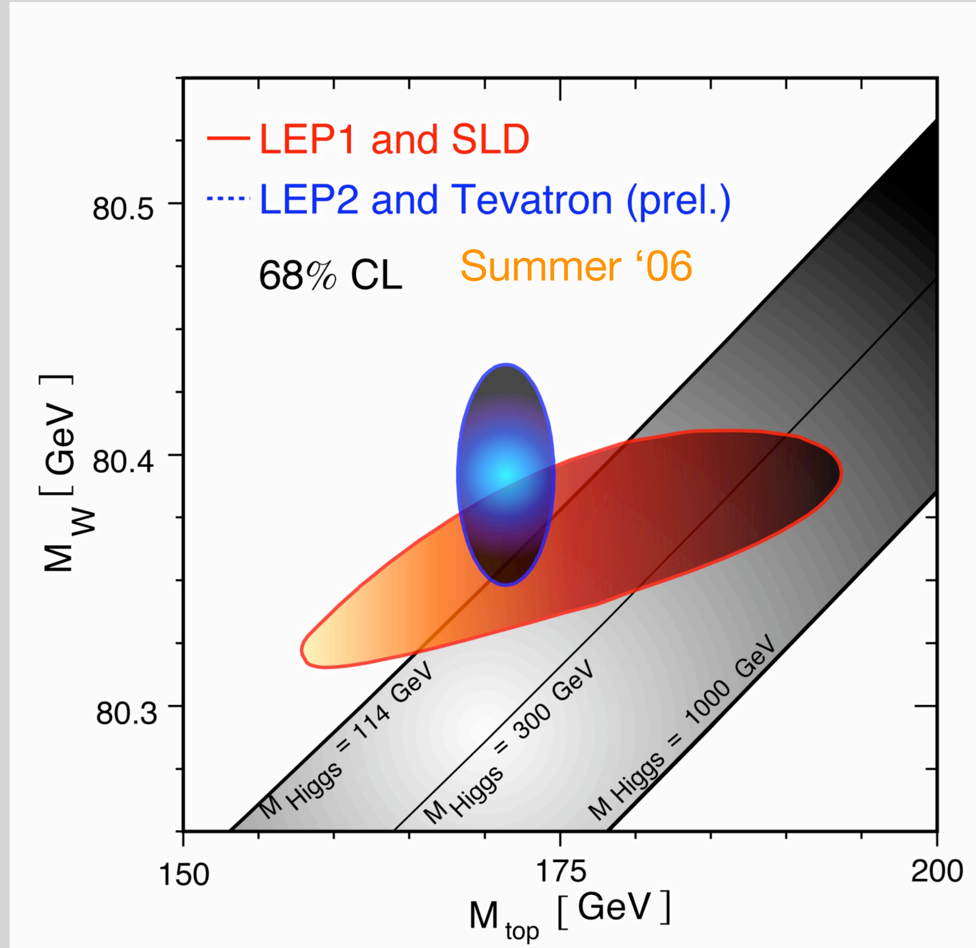
- New more precise measurements in every channel from CDF and D0

- New world average

$$M_{top} = 171.4 \pm 2.1\,GeV/c^2$$

- Present uncertainties on M_{top} and M_W help constrain M_{Higgs} to about 35% $\delta M_{Higgs}/M_{Higgs}$

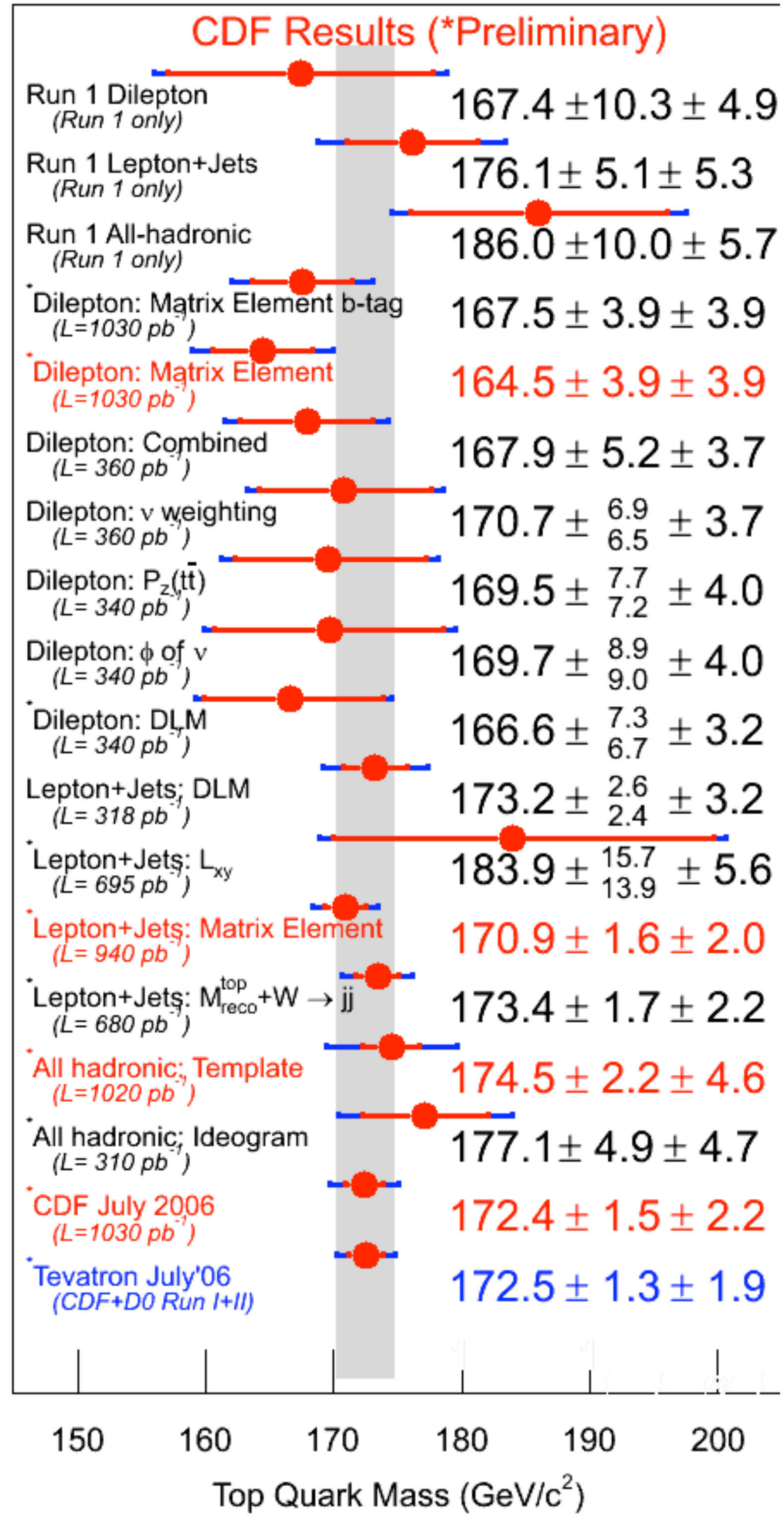
- Tevatron should reach a precision of <1% with the full Run II data set



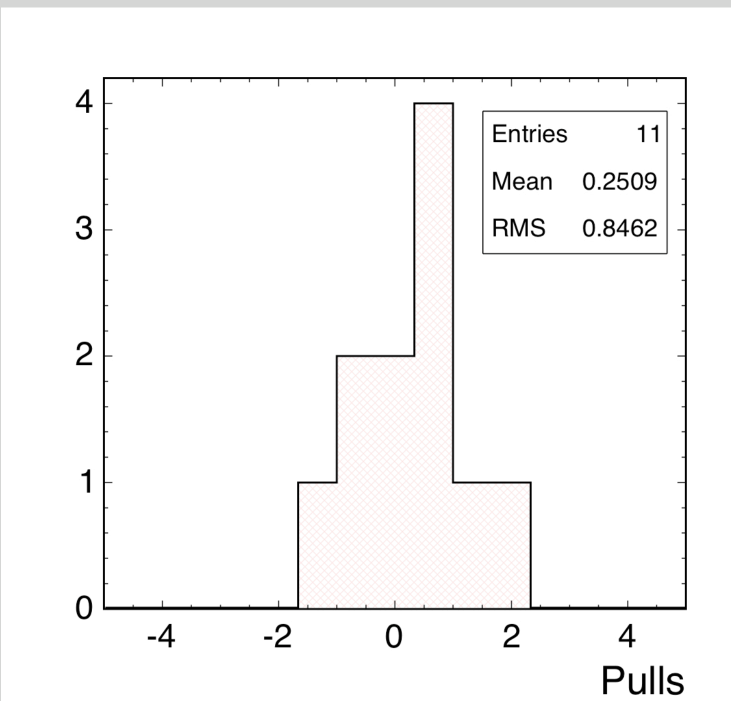
Extra Slides

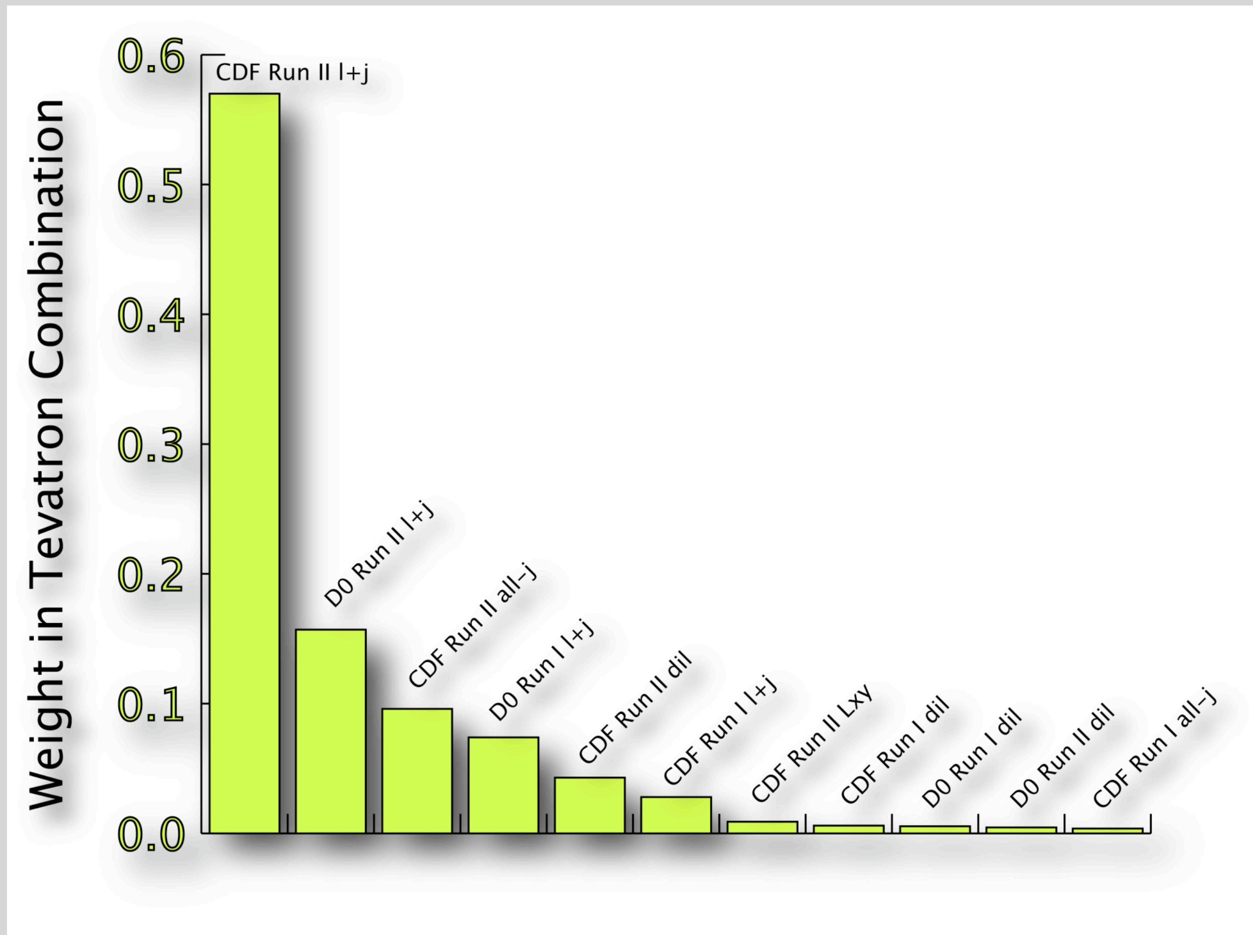
CDF Summary

- In this talk I only showed results with ~$1 fb^{-1}$
- Many other results using different methods underway
- Helps builds confidence in our results
- Improve result combining them



Tevatron combination





CDF combination